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Evaluating The Impact Of Individual Forest Management Practices On Suspended Sediment 2/

by

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The Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) requires the Administrator of the Environmental Protection Agency to develop "(1) guidelines for identifying and evaluating the nature and extent of nonpoint sources of pollutants, and (2) processes, procedures, and methods to control pollution resulting from---agriculture and silvicultural activities, including runoff from fields and crops and forest lands..."

These Amendments give rise to many questions for forest resource planners and managers to answer. For example, what is the present suspended sediment concentration in water coming from forest land? Does this water meet standards for suspended sediment? What is the suspended sediment contribution of each land use or disturbance within the forest? What forest practices or uses are yielding excessive sediment and why? What remedial or managerial measures are required to reduce the sediment contribution to acceptable levels? Can we predict the reduction in suspended sediment due to the remedial measures and the future sediment concentrations with various levels of compliance with recommended sediment control programs?

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The author has developed a procedure to help answer these questions, one that already has been used in river basin planning in the Southeast. It's called First Approximation of Suspended Sediment (FASS). FASS provides river basin and watershed planners, as well as land managers, with a tool to estimate the impact of present management on suspended sediment, identify problems, and evaluate alternative methods to reduce suspended sediment.

FASS Outlined

Briefly, FASS distributes measured sediment yield, either suspended sediment or reservoir sedimentation data, among the land uses and disturbances above the point of measurement. The procedure is based upon a detailed watershed analysis which includes the following major steps:

(1) Stratifying the study area using soils, slope, vegetation, land uses, land disturbances, and quality and type of management.

(2) Field sampling strata for erosion and sediment production.

(3) Computating erosion and estimated sediment production volumes for each land use or disturbance. by Atlanta

(4) Computating gross erosion and estimated sediment production of the watershed.

(5) Distributing measured sediment yield among land uses and disturbances in proportion to their individual contribution to the gross sediment production.

(6) Identifying land uses and disturbances that need their suspended sediment contribution reduced and prescribing corrective measures.

(7) Projecting benefits of recommended sediment control programs.

Stratification

The watershed is stratified using those factors that are likely to affect erosion and sediment yield such as soils, slope, vegetation, land uses, land disturbances, and quality and type of management. For the most part, this can be done from available maps, aerial photos and other information. These factors usually appear on two or more maps and must be combined to form one stratified map. Elliot Amidon's computer mapping program (MIADS 2) is used to assemble these single factor maps into a stratified map and to compute the area of each stratum (2).

Some disturbances such as burns and timber thinnings may not appear on maps or aerial photos. The areas of such disturbances are developed from field sampling or local knowledge.

Field Sampling

Those strata occupying more than one percent of the study area or suspected of having unusual erosion problems are field sampled to develop erosion and sediment production rates. The strata sampled usually comprise more than 95 percent of the study area. Sampling is accomplished by using transects, composed of three one-quarter acre plots with plot center located

200 feet apart, which are located on aerial photos or maps before going to the field. The observer carefully finds the starting point and proceeds in direction prescribed by transect line on the photo or map.

A cross section of conditions are sampled including slope positions—the tops, sides and toes of hills and ridges. Some disturbances, such as logging, require several years to heal. Therefore, the sample includes logging disturbances of varying ages from recent to several years old. Such sampling provides data on recovery trends and an average erosion and sediment production rate for period of recovery.

The areas of disturbances within each plot are then evaluated. For example, a logged area has spur roads, skid trails and landings; therefore, the percent of logged area represented by each of these disturbances is estimated. Knowing the acreage that is logged within the study area, we can calculate the acreage in spur roads, skid trails and landings.

The next step is to compute erosion and sediment production rates for each disturbance within the plot. Sheet erosion is computed by use of the Universal soil-loss equation (8):

$$A = R\ K\ L\ S\ C\ P$$

where A is the computed soil loss per unit area.

R, the rainfall factor, is the number of erosion-index units in a normal year's rain. The erosion index is a measure of the erosive force of specific rainfall.

K, the soil-erodibility factor, is the erosion rate per unit of erosion index for a specific soil in cultivated continuous fallow, on a 9-percent slope 72.6 feet long.

L, the slope-length factor, is the ratio of soil loss from the field slope length to that from a 72.6-foot length on the same soil type and gradient.

S, the slope-gradient factor, is the ratio of soil loss from the field gradient to that from a 9-percent slope.

C, the cropping-management factor, is the ratio of soil loss from a field with specified cropping and management to that from the fallow condition on which the factor K is evaluated.

P, the erosion-control practice factor, is the ratio of soil loss with contouring, strip-cropping, or terracing to that with straight-row farming, up-and-down slope.

For forest conditions, Wischmeier has developed a procedure for approximating the Universal soil-loss equation's cover and management factor C (9).

The observer then estimates, based on visual evidence, what percent of the sheet erosion from each disturbance reaches the nearest stream. This percentage is multiplied times the sheet erosion rate to compute the sediment production rate, which is the rate that erosion reaches the nearest stream. This percentage is estimated by tracing the soil movement downhill, evaluating what soil fractions (sands, silts or clays) are trapped by obstructions such as litter, limbs, logs, depressions, and benches. A tool used for making this estimate is the textural triangle (Figure 1). After the texture of the surface is determined—loam, sandy

loam or whatever--the textural triangle is used to approximate the percentages of sands, silts and clays (1). If the observer finds, for example, only sands being deposited behind obstructions, then the silts and clays are gone. The observer then visually estimates what part of the sands are gone and adds this to the fines to approximate the percentage of soil erosion that reaches the nearest stream.

Many factors are involved in this estimate, but the key is that the observer be consistent. In this procedure it does not matter if the estimate is consistently high or low. The reason will become apparent later.

Next, gully erosion is evaluated within the plot. The observer identifies the cause of the gullies found and measures the parameters for the following equation:

$$G = F \frac{Lg \; X}{Y}$$

G = Gully erosion - Tons/Acre/Yr.

F = Conversion factor of cubic feet to Tons (0.17 Tons/Cubic foot/0.25 Acre Plot)

Lg = Gully length within quarter acre plot - ft.

X = Average gully cross section eroded in years of estimate - Ft^2

Y = Years of Estimate - Years

The sediment production rate for gully erosion is estimated in like manner as for sheet erosion.

An average sediment delivery ratio is computed for each natural, logged, and other stratum by dividing the average sediment production rate by the average erosion rate.

Erosion and Sediment Production By Land Use or Disturbance

The total of sheet and gully erosion for each plot is plotted as a function of the Universal K-factor and slope classes by cause of erosion such as natural erosion and logging (Figure 2). These plottings are used to project an average erosion rate for each stratum. For example, let's assume that a stratum has an average K-factor of 0.32, average slope of 10 percent and is undisturbed. In Figure 2 the projected erosion rate for this stratum is determined by projecting the 0.32 K-factor up to the 10 percent slope line for natural erosion and across the figure to obtain a rate of 0.038 tons per acre per year.

If another stratum had the same K-factor and average slope, yet was logged, a projection of 0.470 tons per year would be obtained. The logged stratum is experiencing two types of erosion: natural or geologic plus accelerated erosion due to logging. Therefore, the average erosion due to logging alone is 0.470 minus 0.038 or 0.432 tons per acre per year. By the same procedure, accelerated erosion from logging and burning over that of logging alone can be determined, or any other combination of causes.

So far, for each stratum, a projected erosion rate and sediment delivery ratio have been developed. A sediment production rate can now be computed by multiplying the projected erosion rate by the sediment delivery ratio.

Gross Erosion and Sediment Production

The volume of erosion produced by each stratum within the basin is calculated simply by multiplying the strata erosion rate by the stratum area. The volume of sediment production for the stratum is computed in like manner. The total volume of erosion and sediment production from forest land is merely the sum of these volumes by disturbances. For an example, see columns 3 and 4 in Table 1.

In river basin planning, the Forest Service and the Soil Conservation Service work together in evaluating erosion and sediment production. The SCS evaluates erosion and sediment production from the nonforested areas, such as agricultural lands, highways, urban areas, and channel erosion. The volume of erosion from forest land is added to the volumes computed by the SCS to produce the gross erosion for the basin.

Distributing Sediment Yield

What has been accomplished so far is to determine what proportion of the erosion and sediment production that can be attributed to each forest disturbance. The fact that sediment production volumes have been only estimates is of little consequence; in this part of the procedure these volumes will be determined more accurately. Two approaches may be followed depending on what downstream sediment yield data is available.

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Using Suspended Sediment Data

The preferred approach is to use suspended sediment data, if it is available because the main objective is to evaluate water quality impact. Table 1

contains a representative example, the Santee River Basin in South Carolina, with the causes of erosion on forest land listed in column 1 and the corresponding area of each disturbance in column 2. Forests occupy 6.5 out of 10.3 million acres or 63 percent of the area.

The computed erosion by cause is presented in column 3. In this case, forest land produces 4,454,300 tons per year---approximately 10 percent of the gross erosion for the basin.

Column 4 contains the estimate of how much erosion by cause reaches the stream. These volumes are added to produce a total estimated sediment production. The amount by cause is divided by the total to produce the proportion of estimated sediment production (column 5). Thus, these proportions identify the relative importance of each disturbance as a sediment producer and a water polluter within the forest.

In this basin, the average suspended sediment concentration is 340 mg/l. It is assumed that the proportion of suspended sediment contributed by the forest and forestry activities approximately equals the ratio of forest erosion to basin erosion. In this example, it is 10 percent or 34 mg/l. The 34 mg/l is multiplied by the various proportions of estimated sediment production (column 5) to compute the average annual suspended sediment contribution by each cause of erosion found in column 6.

The Santee basin has reservoirs that trap slugs of muddy stormflow. The muddy water adversely affects recreation and fisheries because the suspended

sediment requires an extended period of time to settle; therefore, the impact of forestry activities on water quality of stormflows should be evaluated. Stormflow volumes were computed using USGS Water Supply Papers and the following ride of thumb (6):

$$N = A^{0.2}$$

where N = time in days for terminating direct runoff.

A = drainage area in square miles.

How many days to consider as stormflow

The streamflow volumes from the first significant rise to N-days after the peak were added to approximate the stormflow. The sum of the stormflows is the stormflow volume for a year. For the period of study, the annual stormflow volumes are averaged. For this basin, stormflow volume equals approximately 44 percent of the average annual flow.

Research has generally demonstrated that approximately 90 percent of sediment yield occurs during stormflow periods (4,5). So the average suspended sediment concentration for stormflow is computed with the following formula:

$$WQ_s = \frac{0.90\ WQ_m}{Q_s} = \frac{0.90\ (340\ mg/l)}{0.44} = 695$$

(7)

Where:

WQ_s = Average suspended sediment concentration (mg/l) in stormflow

WQ_m = Average annual suspended sediment concentration (mg/l).

Q_s = Proportion of annual runoff contributed by stormflow.

Therefore, the average stormflow concentration is 695 mg/l of suspended sediment, of which forest is allotted 10 percent or 69.5 mg/l. This volume is distributed among the causes of erosion, following the procedure used to compute the average annual suspended sediment, and is presented in column 7.

The forest manager is also concerned about the baseflow water quality because fish, although they can stand short periods of high sediment concentrations, need high quality water on a continuing basis for good reproduction and growth. If 90 percent of the sediment is yielded during stormflow periods, then baseflow must yield 10 percent. For this example, 56 percent of the annual flow is baseflow. Therefore, the average suspended concentration during baseflow is :

$$WQ_b = \frac{0.10\ WQ_m}{Q_b} = \frac{0.10\ (340\ mg/l)}{.56} = 61\ mg/l$$

Where:

WQ_b = Average suspended sediment concentration (mg/l) in baseflow.

WQ_m = Average annual suspended sediment concentration (mg/l).

Q_b = Proportion of annual runoff contributed by baseflow.

Consequently, the average baseflow concentration is 61 mg/l with 6.1 mg/l assigned to forest land. In Column 8, this allotment is again distributed among the causes of erosion. Thus ends the procedure when suspended sediment data is available.

Using Reservoir Sedimentation Data

Water quality impacts also can be evaluated using reservoir sedimentation data, an example of which is presented in Table 2. The reservoirs in the Santee Basin trap 6,174,000 tons of sediment per year, and again the forest is allotted 10 percent or 617,400 tons per year. This portion is allocated to the causes of erosion, using the same proportions of estimated sediment production as in Table 1, Column 5. Column 3 in Table 2 contains this apportionment. Column 4 in Table 2 contains the average sediment yield rate, which is the quotient of sediment yield divided by the area of each disturbance.

Reservoir sediments are delivered as either bedload or suspended soil particles. The proportion delivered as suspended sediment can be approximated from soils data and knowledge of the stream. For example, a slow moving stream carries only silts and clays in suspension, while faster flows can suspend sands and larger materials.

The Santee River is a relatively slow moving stream with silts and clays assumed to be the predominant materials in suspension. Silts and clays average 55 percent for the soils in this basin. Because most causes of erosion occur throughout the basin, sediment yield rates were multiplied by 0.55 to approximate the rate at which fines are contributed by each disturbance (column 6). An exception was mechanical site preparation which was confined to a belt of clay loam soils that average 65 percent fines.

This procedure is based upon a unit area concept and converting the average yield of fines to suspended sediment concentrations. Therefore, in column 7, the area of each disturbance is expressed as a proportion of unity or a representative acre.

Conversion factors are developed for a ton of suspended sediment to milligrams per liter of annual, base and storm flows. For this basin, these flows equal 17.0, 9.5, and 7.5 inches, respectively. The conversion factors are as follows:

Stormflow	1,177 mg/l/ton
Baseflow	929
Annual Flow	520

Finally, three simple formulas are used to compute average sediment concentrations by disturbance for the three types of flow:

SSa = Ka(S) (A) where:

SSa = Average annual suspended sediment concentration - mg/l

S = Average annual yield of material assumed to be carried in suspension in tons per acre per year

A = Proportion of representative acre occupied by the disturbance

Ka = Conversion factor for average annual flow - mg/l/ton

SSb = 0.1 (Kb) (S) (A) where:

SSb = Average suspended sediment concentration for baseflow -mg/l

Kb = Conversion factor for baseflow - mg/l/ton

SSs = 0.9 (Ks) (S) (A) where:

SSs = Average suspended sediment concentration for stormflow - mg/l

Ks = Conversion factor for stormflow - mg/l/ton.

In Table 2, the suspended sediment concentrations presented for annual, storm and base flows in columns 8, 9 and 10, respectively, are slightly lower than corresponding values in Table 1, but both procedures provide approximately the same answers for this example. The difference may be caused by some fine sands being carried in suspension.

To complete the picture for forest land, any channel erosion occurring would be evaluated separately. Although the Santee study did not quantify suspended sediment from channel erosion, some research by Lull and Reinhart (7) can be used to approximate the magnitude of this source. They reported that, for forested watersheds in the east, nonstorm periods had turbidities of 2 to 5 ppm and stormflow was generally under 10 ppm. They attribute these turbidities to stream channel erosion. At these low concentrations, parts per million is essentially equal to milligrams per liter. Therefore, 2 to 5 mg/l should be added to baseflow, 10 mg/l to stormflow, and approximately 8 mg/l to annual concentrations to complete the picture for forest lands. These channel erosion contributions to suspended sediment are entered in Tables 1 and 2 in parentheses and added to that for forest land.

Identifying Sediment Problems and Corrective Measures

The question now arises, is the forest yielding water that meets water quality criteria for uses downstream? Suppose the water is used for recreation and fishing, and has maximum and optimum criteria of 50 and 5 mg/l respectively (3). The 50 mg/l could be set as a goal for stormflow with the 5 mg/l as standard for baseflow. As said before, fish can tolerate

short periods of high concentrations, but need high quality water most of the year for optimum reproduction.

Either Tables 1 or 2 could be used for this evaluation, but Table 2 is selected because it shows the importance of each disturbed area in sediment production more clearly. The data indicate that the forest is not yielding water that meets these criteria.

What land management activities are causing the problem? Mechanical site preparation is the biggest contributor followed by channel, fire and skid trail erosion. Obviously, not much can be done to reduce channel erosion, but the others can be alleviated.

Three basic actions can be taken to reduce the suspended sediment contributions: (1) install filter strips between disturbances and streams, (2) reduce on-site erosion rates, and (3) reduce the area of disturbance. Sometime during field sampling, good management should be evaluated for erosion and sediment production rates. Also, filter strips should be evaluated for trap efficiency. On-site erosion rates can be reduced by limiting the percent of bare ground, slope, and slope lengths allowed for various management activities based upon observations made in well managed areas.

Projecting Benefits of Sediment Control Programs

The benefits from these recommendations can be evaluated by using the data from well managed areas and/or the Universal equation. The reduced erosion

should produce at least a proportional reduction in suspended sediment. These projected data are run through FASS to predict what the water quality would be under recommended management and compare the results with water quality criteria.

If reducing erosion rates and installing filter strips are not enough to meet water quality criteria, then the area of disturbances must be reduced. Suspended sediment reductions should be proportionated to the area reduction for each disturbance.

Limitation of Use

FASS should not be used if large swamps lie between the disturbance and the point of measurement unless the trap efficiency of the swamp can be determined. If a swamp lies in the headwaters and yields large quantities of suspended colloidal materials, or colored water, FASS should not be used unless the mix of suspend materials is quantitatively and qualitatively analyzed.

Summary and Conclusions

FASS is a technique for evaluating land management with respect to water quality insofar as it is affected by suspended sediment. It provides a means of identifying the causes of water quality problems, and identifying and evaluating land management changes needed to meet water quality standards. It also can be used to predict the consequences of any proposed activity.

To strengthen FASS results, all lands including forests, agriculture,

construction and roads, need evaluation by the procedure. Measured sediment yield would then be distributed among all land uses or disturbances based upon their estimated sediment production. This would eliminate the use of the assumption that sediment yield from forest land is proportional to its proportion of gross erosion.

Table 1 - Water Quality Impact Evaluation Using Suspended Sediment Data 2/

(1) Cause of Erosion	(2) Area Acres	(3) Erosion Tons/year	(4) Est. Sediment Production Tons/year	(5) Proportion of Est. Sediment Production	(6) Average Suspended Sediment MG/L	(7) Average Suspended Sediment in Storm Flow Period MG/L	(8) Average Suspended Sediment in Base-flow period MG/L
Natural	6,500,000	499,100	0	0			
Logging	294,000	525,900	7,500	0.006	0.2	0.4	T
Fire	48,300	395,600	126,500	0.099	3.4	6.9	0.6
Skid Trails	5,400	347,400	85,900	0.067	2.3	4.7	0.4
Spur Roads	1,100	69,700	23,600	0.019	0.6	1.3	0.1
Landings	1,700	11,000	800	0.001	T	0.1	T
Mechanical Site Preparation	30,400	2,605,600	1,030,100	0.808	27.5	56.1	5.0
Subtotal-Forest Land	6,500,000	4,454,300	1,274,400	1.000	34.0	69.5	6.1
Channel Erosion					(8) 1/	(10)	(3)
Forest land and Channel Erosion					(42.0)	(79.5)	(9.1)
Basin Totals	10,300,000	45,312,600			340.0	695.0	60.7
Forest Proportion	0.63	0.10			0.10	0.10	0.10

1/ Suspended sediment from stream channel erosion. (Lull and Reinhart, 1972)

2/ Data prepared for the Santee River Basin Study, South Carolina

Table 2 - Water Quality Impact Evaluation Using Reservoir Sedimentation Data 2/

(1) Cause	(2) Area Acres	(3) Sediment Yield Tons/Yr.	(4) Average Sediment Yield Rate Tons/Ac/Yr.	(5) Proportion of Fines in Soils	(6) Average Yield of Fines Tons/Ac/Yr.	(7) Proportion of Forest Area	(8) Average Suspended Sediment MG/L	(9) Stormflow Suspended Sediment MG/L	(10) Baseflow Suspended Sediment MG/L
Natural	6,500,000	0	0		0	0.9414			
Logging	294,000	3,700	0.013	.55	0.007	0.0452	0.2	0.3	T
Fire	48,300	61,100	1.265	.55	0.696	0.0074	2.7	5.4	0.5
Skid Trails	5,400	41,400	7.667	.55	4.217	0.0008	1.5	3.5	0.3
Spur Roads	1,100	11,700	10.636	.55	5.850	0.0002	0.6	1.2	0.1
Landings	1,700	600	0.353	.55	0.194	0.0003	T	0.1	T
Mechanical Site Preparation	30,400	498,900	16.411	.65	10.667	0.0047	26.0	53.1	4.7
Subtotal Forest Land	6,500,000	617,400	0.095		0.060	1.0000	31.2	63.6	5.6
Channel Erosion							(8) 1/	(10)	(3)
Forest land and Channel Erosion							(39.2)	(73.6)	(8.6)
Basin Totals	10,300,000	6,174,000							
Forest Proportion	0.63	0.10							

1/ Suspended sediment from stream channel erosion. (Lull and Reinhart, 1972)

2/ Data prepared for the Santee River Basin Study, South Carolina

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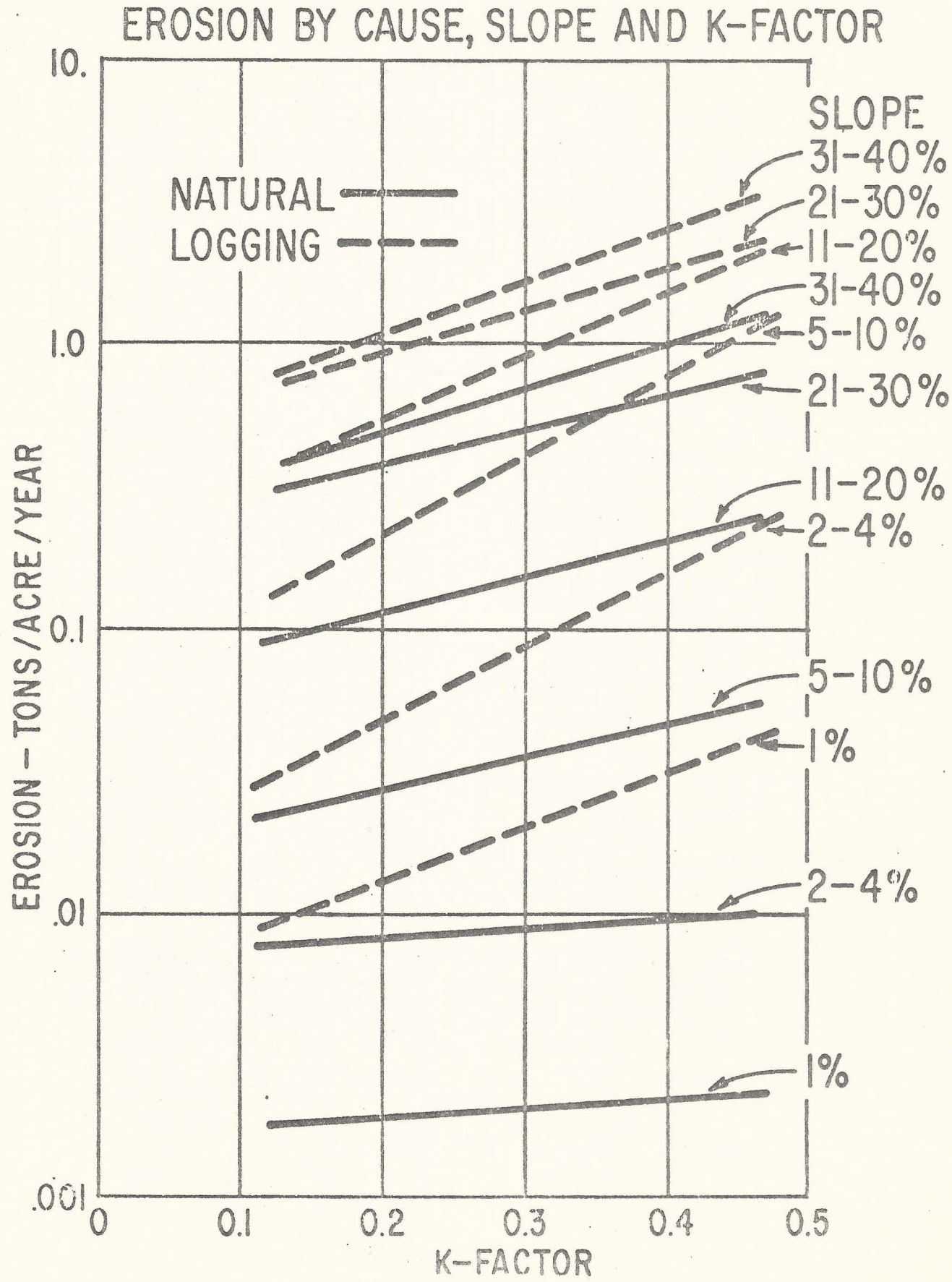
EROSION BY CAUSE, SLOPE AND K-FACTOR
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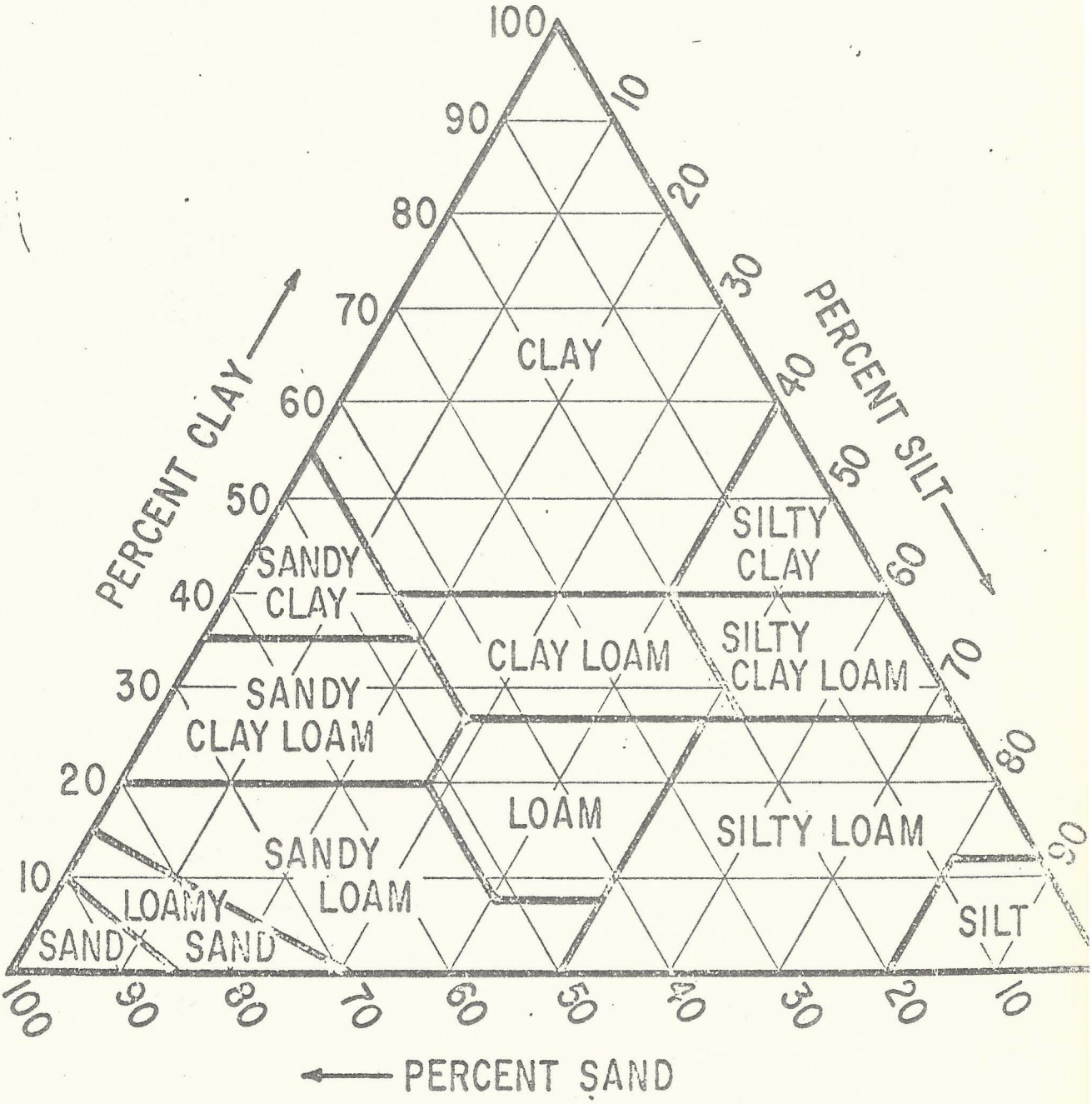
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